Development of an Electronically-Controlled Smoke Pot Aerosol Dispenser[1]

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ABSTRACT

Engineering Technology, Inc. (ETI) and the U.S. Army Edgewood Chemical and Biological Center (ECBC) have completed the technology application demonstration of a general-purpose Smoke Pot having an electronic controller. The smoke pot employs propellant-based aerosol dissemination technology to expel obscurant materials. A patent is currently pending for this dissemination technology. The smoke screen produced by this device is effective in the visual (VIS), infrared (IR) or milllimeter (MM) radar spectrum. Each smoke pot is integrated into a standard M2A1 ammunition container for convenience in handling, storage and use. The total weight of the prototype device is 32 lbs. The smoke aerosol material is loaded into 18 separate chambers. An electric igniter initiates each chamber.

The smoke pot's battery-powered, electronic controller allows this operator to control the rate of smoke production by the pot, the time at which the unit will start to function and how much of the total payload will be expelled. The controller may be set to produce a single, instantaneous cloud of very dense smoke or a continuous curtain of smoke for up to 1 minute's duration. This capability provides broad utility for the smoke pot and allows one or more units to be used in a pre-planned, coordinated event.

This device is well suited to military operations in urban terrain (MOUT) scenario where it would allow troops to move from building to building over several city blocks under cover of smoke. It would also be effective as a sniper countermeasure, diversion and distraction and crowd control. A turret-mounted adaptation in conjunction with threat warning sensors could be employed for vehicle self-protection smoke applications.

1. BACKGROUND

The Smoke Pot concept is an extension of the 40mm screening cartridge work that was previously performed by ETI.[2] The basic packaging and dissemination technology was extended to include multiple cartridges, an electric initiation method instead of a percussion primer, and a self-

[1] This work was funded by U.S. Army SBCCOM under the terms of contract number DAAD13-98-C-0043.
[2] Mills, T.E, "Development of a Cartridge for Aerosol Dissemination", Proceedings of the Smoke/Obscurants Symposium XX, ERDEC-CR-270, December 1988, pp 231-240

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contained control system. ECBC's Advanced Protection Technology (APT) Team conceived a concept by which the 40mm IR/MM/VIS wavelength screening cartridges are incorporated into a stand alone sequencing and firing mechanism to provide a continuous screening or rapid screening capability. The concept was termed the IR/MM/VIS Smoke Pot. An illustration from the original concept phase is shown in figure 1.

2. HARDWARE DESCRIPTION

The smoke pot housing is a standard ammunition canister approved for storage, handling and commercial shipment of this class of ordnance. A solids model of the smoke pot aerosol dispenser unit is shown in figure 2. This unit is 11 inches long, 7 inches high and 5.7 inches wide with a maximum weight of 32 pounds when filled with brass powder for IR screening. The Smoke Pot contains 18 separate chambers in a vertical orientation. The construction of these chambers is generally consistent with the prior 40mm IR/MM/VIS cartridge design cited in reference 2.

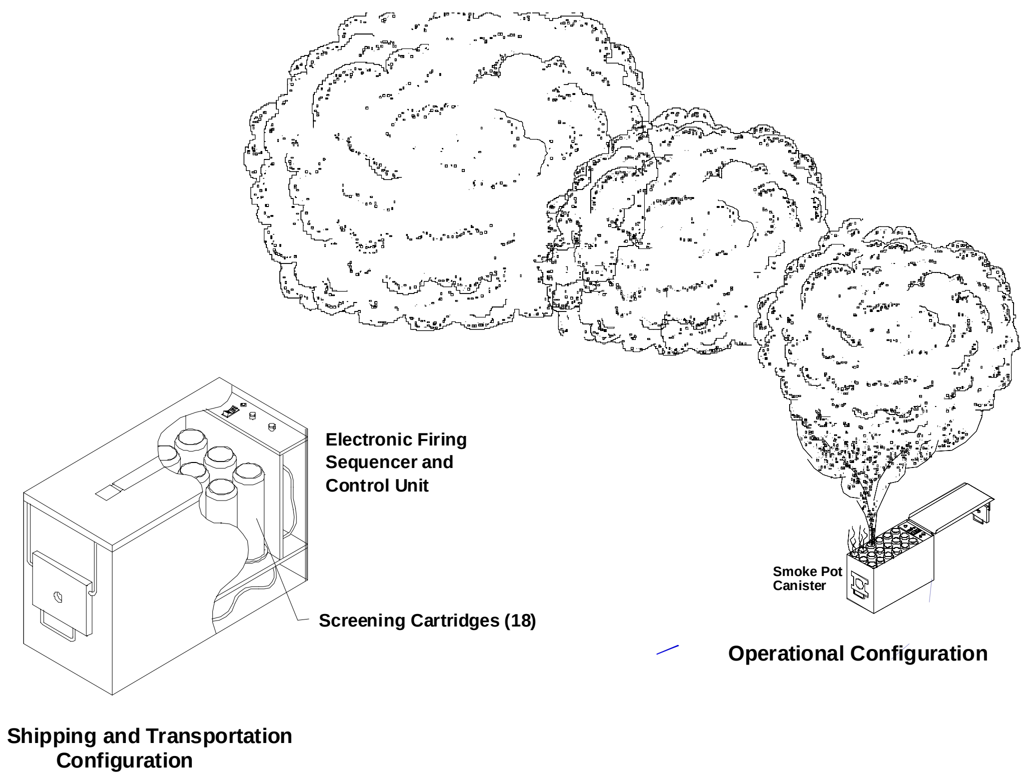


Figure 1. Conceptual illustration of electronically controlled smoke pot aerosol dispenser.

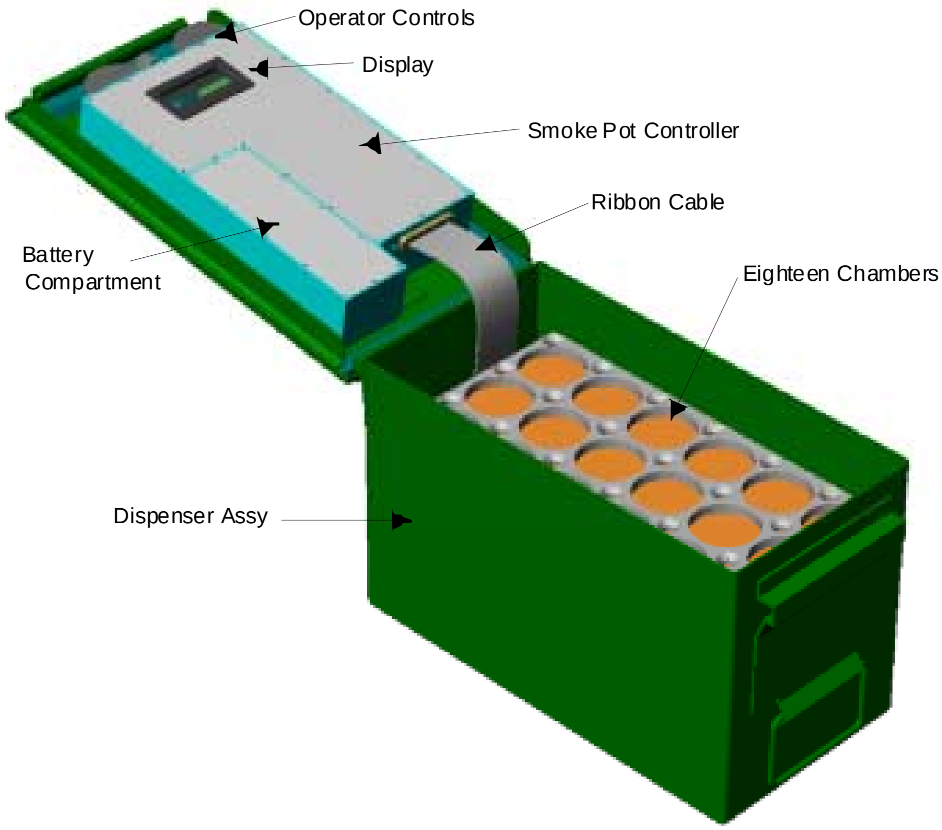


Figure 2. VIS/IR/MM smoke pot aerosol dispenser unit.

An electrically initiated primer, shown in figure 3, replaced the percussion primer used in the screening cartridge design. The propellant is a very fast burning, smokeless cartridge propellant. The propellant cavity is separated from the payload fill section by a diffuser plate, a paper seal and a cloth felt wafer. This diffuser plate contains seven circular holes that allow the propellant combustion gases to flow into the payload fill. A paper membrane precludes the powder material in either the propellant or payload sections from intermixing prior to ignition. A felt wafer is added to the base of the payload chamber. This wafer is cut to a diameter slightly larger than the inside diameter of the chamber. The felt allows the propellant gases to pass through the fabric weave to pressurize the payload chamber prior to rupture of the burst diaphragm. Once the rupture disk bursts, the payload is expelled with the felt wafer being the last material forced from the chamber. As the wafer is expelled from the chamber, it wipes the chamber clean of any loose, retained powder, leaving no residual material in its wake.

The screening agent employed for visual screening is a fine titanium dioxide (TiO_2) powder. No additives were introduced into the TiO_2 fill. This material is used for the smoke fill in the M82 training smoke grenade. The infrared screening agent is brass flake powder of the same type used in the M76 screening grenade. Special tooling was developed for use in packing the fill under a high load by means of a manual press. This tooling allowed for trapped air to escape from the payload fill chamber during the loading operation without loss of the finely powdered fill.

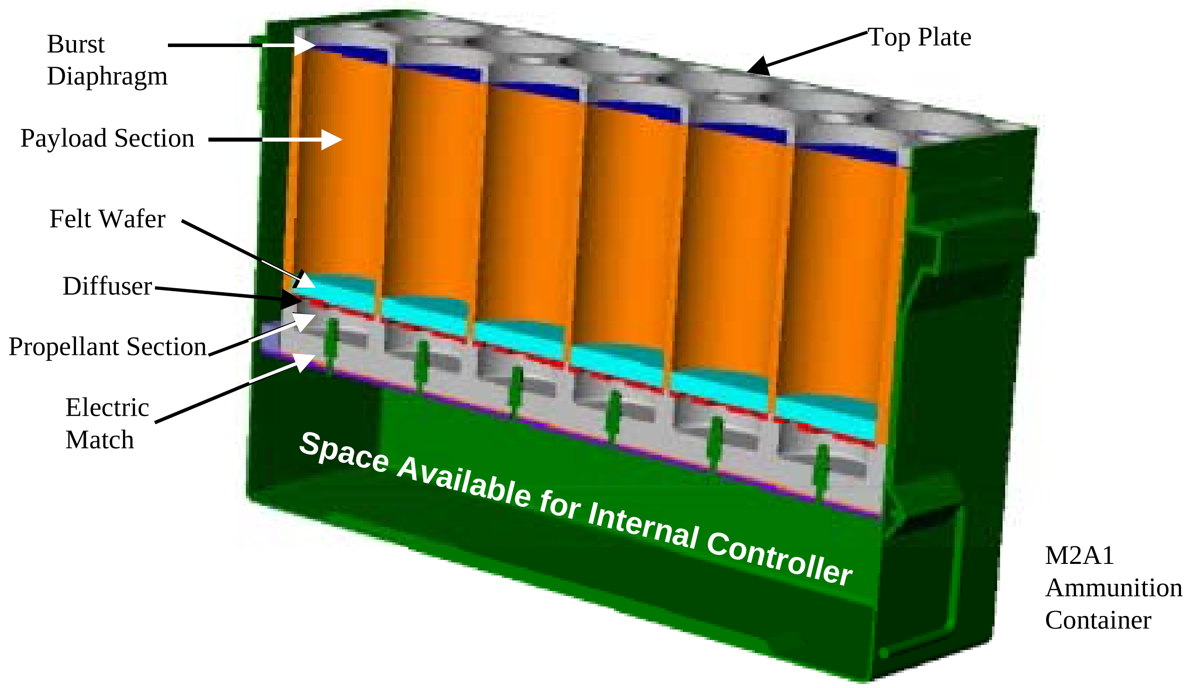


Figure 3. Cutaway section view of obscurant chamber configuration.

The millimeter-screening fill is chopped graphite fiber. Two fill configurations, aligned fiber wafers and DensePack™, were tested. DensePack consists of two-dimensional bundles of chopped fiber cut from a single tow. These flat chips are arranged in a co-planar manner within the payload volume with a random fiber directional alignment in the horizontal plane. The aligned fiber wafers consist of a co-axial bundle of chopped fibers held in vertical alignment with an external circular ring. The packaging densities of the aligned fiber wafers are higher than that of DensePack.

Each of the 18 chambers is 40mm (1.6 inches) in diameter with an overall height of 12.7 cm (5 inches). The total fill weight per smoke pot unit is 7.1 pounds of TiO_2 fill, 10.3 pounds of brass flake or 3.8 pounds of chopped graphite fiber.

The rupture diaphragm is a single brass shim that is retained between the top plate and the cylinder block. The clamping force provided by the threaded fasteners, which attach the top plate to the cylinder block, hold the diaphragm in place against the high pressures generated by the propellant gas generator function until ultimate failure loads are generated. The sharp edge generated on the lower surface of the top plate during manufacture was retained so that a repeatable failure pressure was obtained resulting from a pure shear failure. The burst pressure is determined by the thickness and material properties of the brass used to form the diaphragm.

An electronic control system provides safe and arm and sequencing functions to the smoke pot. The system controls the cartridge firing start delay, the number of firings and the firing interval. A summary of the smoke pot controller features is listed below:

- Power On/Off toggle switch
- Eight character LED display to show set-up function and time interval in seconds and milliseconds
- Rotary encoder switch to adjust function delay and chamber sequencing interval and select the number of chambers to be fired
- Arm switch to start user set safe separation time (not less than 2 minutes)
- Ability to function 18 electric squibs at the user specified interval
- Battery operated (two commercial "D" cell disposable batteries)

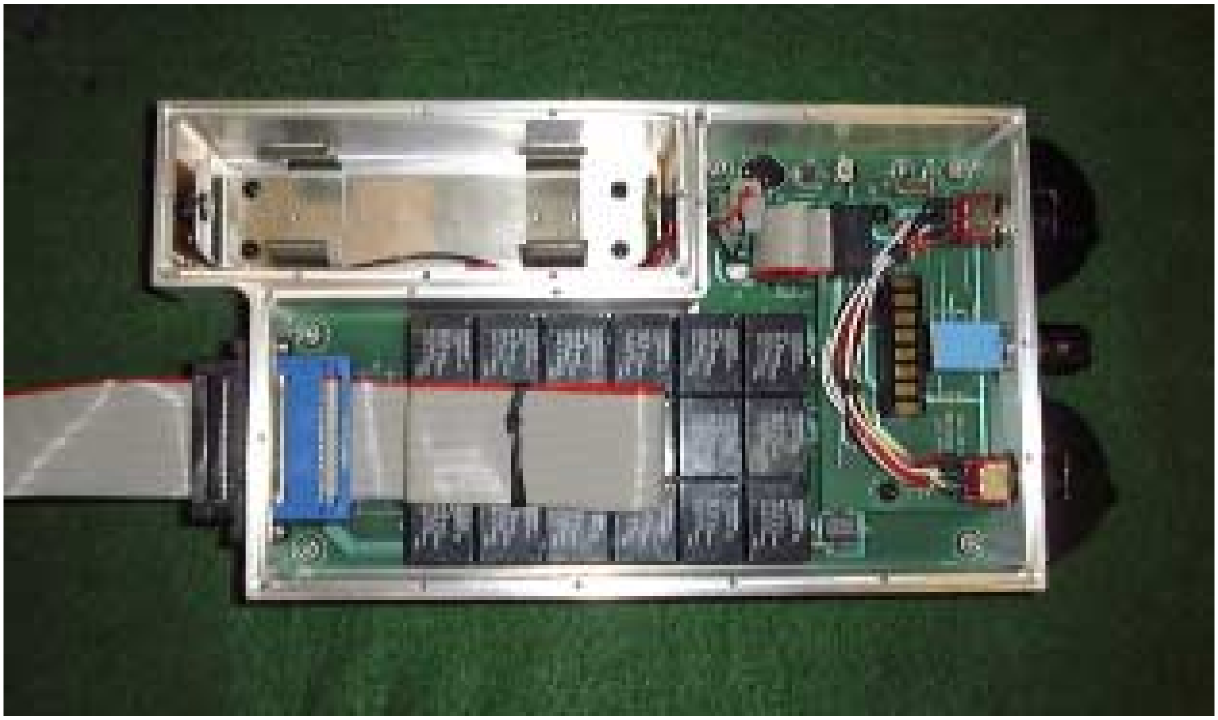
The controller was designed in an integrated and compact fashion so that it could be housed inside the ammunition box along with the dispenser body, producing a totally self-contained, portable unit. Photographs of the electronic controller are provided in figure 4. The electronic control system is attached to the inside of the ammo box lid. A single ribbon cable transfers the firing signals from the controller on the lid to the dispensers in the box. This ribbon cable is disconnected from the controller during shipping and storage for added safety. Internal batteries eliminate the need for an external power source.

In operation, the user anchors the box down on the terrain and opens the lid to expose the control panel and the internal smoke cartridges. The ribbon cable is then connected to the controller. A power switch turns the control system on. A knob is used to set the desired safe separation time delay, the number of chambers to be fired and the time delay between individual chamber initiation. As the settings are made, this information is displayed to the user on an LED display. Once the desired operational parameters are set, an arm switch is actuated and the safe separation countdown begins. After the safe separation countdown is completed, the unit begins to initiate the selected number of cartridges with a time delay between each cartridge as set by the user. When required, the control system produces a current greater than the all-fire current at each of the 18 firing circuits. The burning match in turn ignites a small propellant charge that burns rapidly, producing pressure inside the obscurant chamber. As the propellant composition burns, the gas produced flows into the payload chamber and intermixes with the particulate obscurant fill to promote deagglomeration. When the pressure reaches approximately 1200 psi, a brass burst diaphragm ruptures, allowing the obscurant to be disseminated.

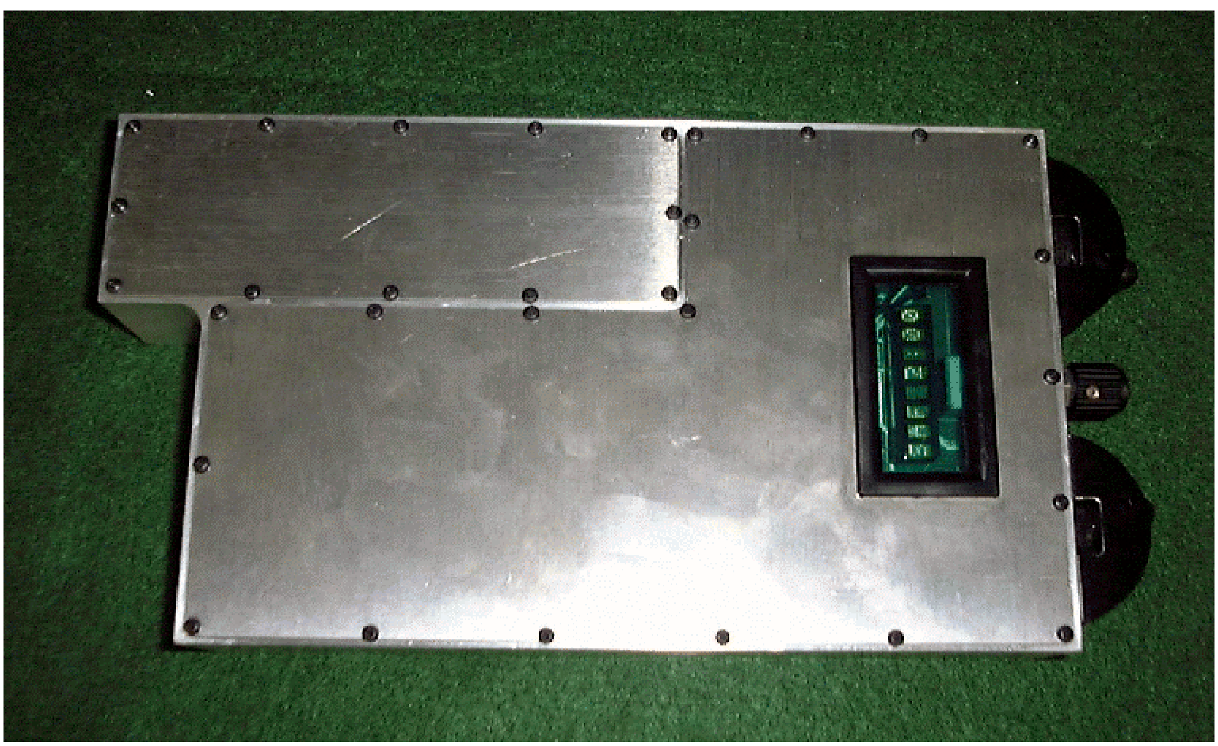
A photograph of a smoke pot unit emplaced and ready for operation is provided in figure 5. In this instance, the unit is embedded into the ground at an angle relative to the ground surface to anchor the unit down and promote overlapping between the individual puffs produced by each chamber in order to form a single continuous curtain of smoke. A summary of the physical properties of the smoke pot is provided in Table 1.

3. PERFORMANCE

Figure 6 provides a sequence of frames from the functioning of a single brass flake filled chamber. These frames illustrate the rapid development of individual puffs from each chamber. The persistence of the brass flake powder aerosol suspension from the device proved to be of a high quality. The outline of the puff boundary is illustrated in figure 7.



4a. Controller circuit card assembly and battery compartment.



4b. Smoke pot controller assembly with operator switches and display.

Figure 5. Smoke pot unit emplaced and ready for function.

Table 1. Physical specification summary for smoke pot aerosol dispenser.

Overall Size (inches)	11.0" L x 7.0" H x 5.7" W		
Number of chambers	18 per unit		
Chamber size	40mm diameter, 12.7 cm long		
Weight , empty (lbs)	21.7		
Payload Fill	Visual	Infrared	Millimeter
- screening agent	TiO_2	brass flk	carbon fiber
- fill mass per smoke pot	7.1 lbs	10.3 lbs	3.8 lbs
Total Unit Weight (lbs)	28.8	32	25.5
Propellant Description	fast burning, smokeless powder; 2 to 3 grams		
Igniter	electric match		
Internal Battery Power	Commercial 'D' Cell, 2 required		
Chamber burst pressure	1200 psi		
Electronic Controller Settings			
- safe separation delay	2 to 10 minutes, 1 sec. increments default is 2 minutes		
- number of chambers	1 to 18, default is 18		
- firing interval	0.1s to 5.0 s, 0.1s increments		

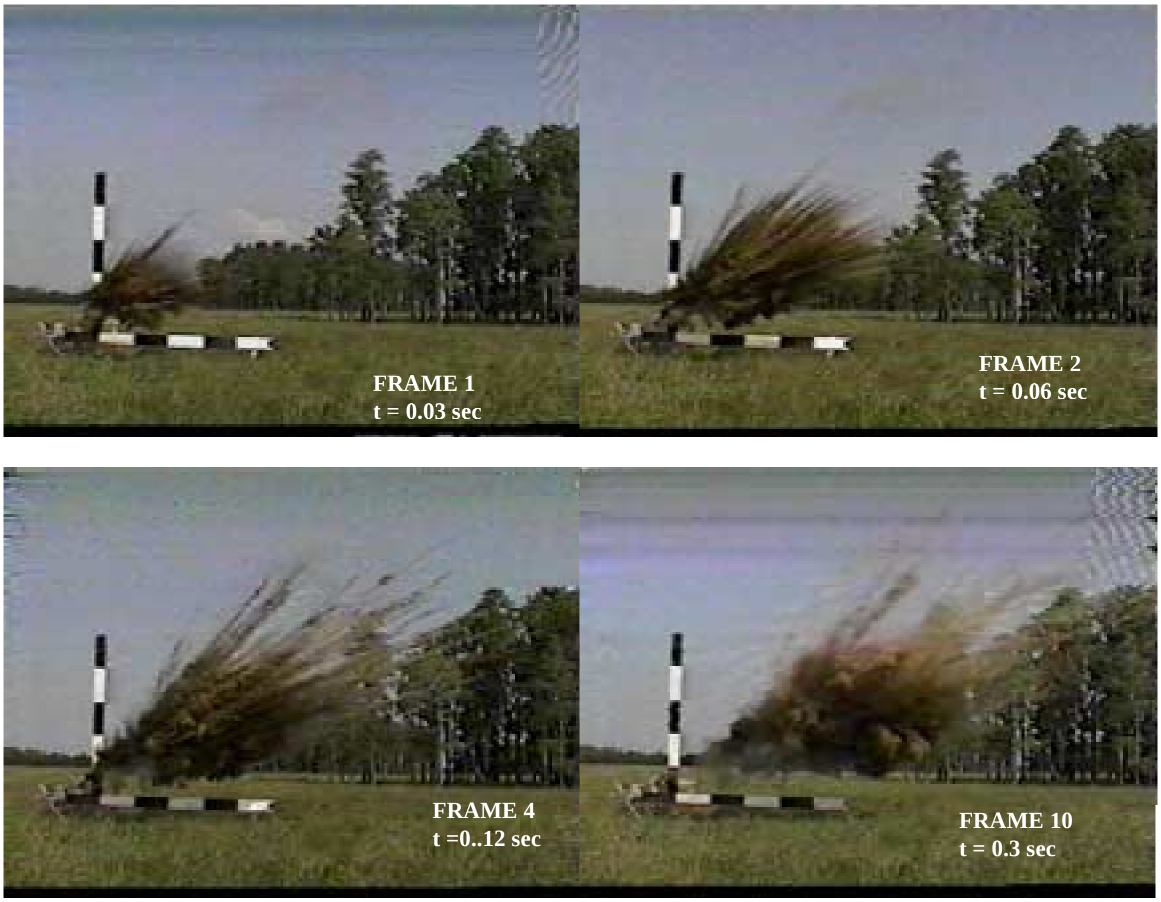


Figure 6. Puff development from a single chamber function.

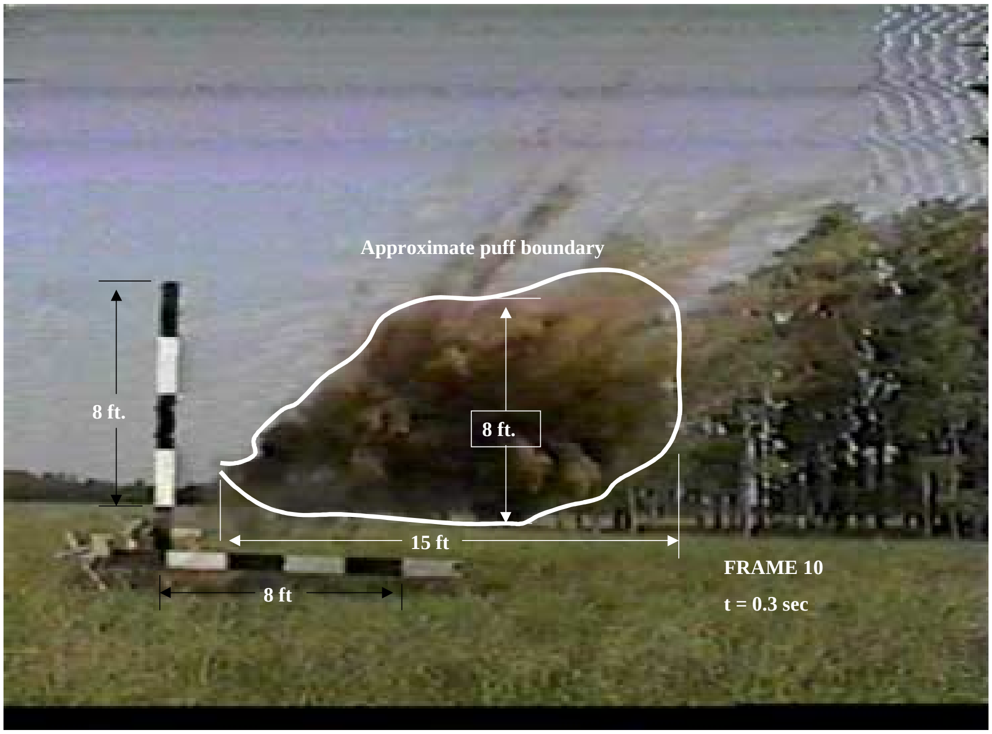


Figure 7. Initial puff size and quality produced from a brass flake filled chamber firing.

Single chamber firings of the carbon fiber filled MM smoke pots were also conducted. The dissemination quality from both the aligned fiber wafer filled units and DensePack filled chambers was less than desired, although the wafer fill units appeared to perform the better of the two. The puff produced from a single DensePack filled chamber is shown in figure 8. While no quantifiable measurements were obtained, both fill methods produced a greater population of agglomerated, or bird-nested, clumps than anticipated. The degree of agglomeration was visually apparent in the aerosol cloud and evidenced in the ground fallout in the immediate vicinity of the firing stand. It is expected that these clumps are a result of the rapid end-extrusion expulsion mechanism employed by the smoke pot. It is not apparent that there is a mechanism for reducing this agglomeration to a significantly lesser extent for this device. A propellant actuated cartridge, which expelled the carbon fiber payload radially from the centerline of the device, would be expected to yield a more monodisperse aerosol result.

The screening effectiveness of the visual TiO_2 was equally disappointing. The ideal mass extinction coefficient for TiO_2 is roughly three times that of brass flake in the visible spectrum, while the mass loading of the brass filled chambers is 30% greater than that of the TiO_2 fill. One would anticipate that the visual screening effectiveness of the visual fill would be better than that of the IR fill. However, this was not borne out in our test results. Again, particulate agglomeration was the cause. The fine particulate TiO_2, having a large surface area, tends to agglomerate to a much higher degree than the larger, heavier brass flake powder. These tendencies are well documented in powder handling and processing literature where TiO_2 powders are widely recognized as problematic from a flow perspective[3,4]. When this material is consolidated under the pressure of the loading press, agglomeration is promoted. The

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[3] Classification and Definition of Bulk Materials, Conveyor Equipment Manufacturer's Association, Book No. 550, 1970

[4] Carr, R.L., Classifying of Flow Properties of Solids, *Chemical Engineering*, Jan 18, Feb 21, 1965. Published by McGraw-Hill, Inc.

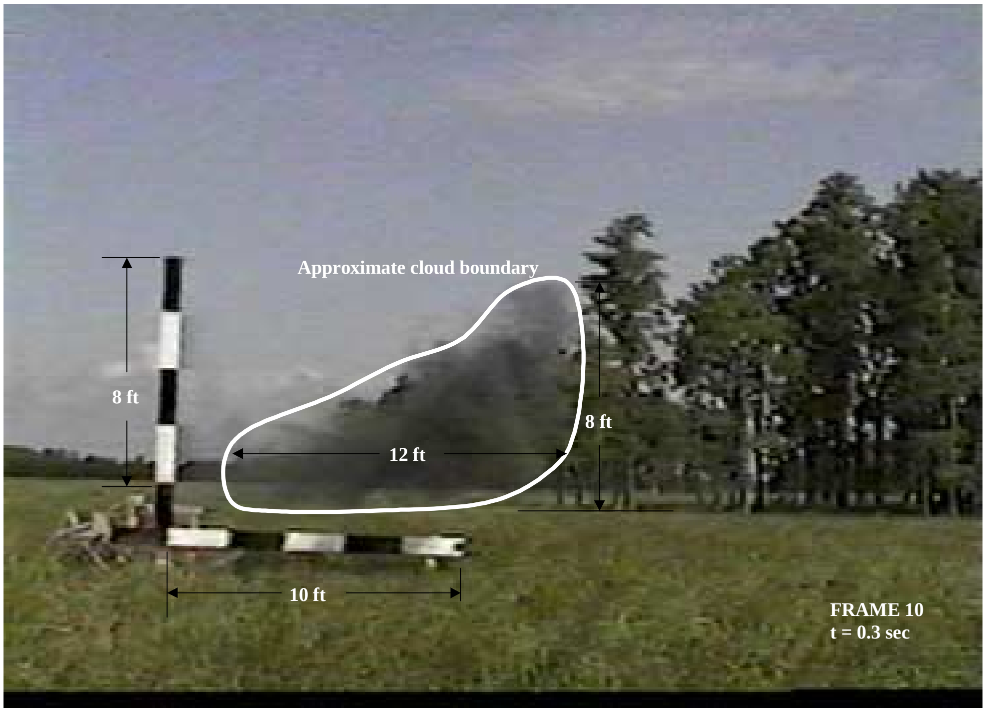

Figure 8. Initial puff size and geometry from a carbon fiber filled chamber firing.

energy of the expulsion event is not sufficient to break these large bundles of agglomerated $TiO_{2.}$. Evidence of this was observed by the white, flakey "chips" observed in the deposition immediately adjacent to the firing stand. As with the MM fill, it is unclear how this agglomeration can be corrected for the densely filled TiO_2 smoke pots. The shock and brisance produced by the explosive dispersal of TiO_2 in the M82 training grenade may separate these clumps to a greater degree.

Once the initial testing was complete, ETI fabricated 18 prototype units for use in a series of technology demonstration firings conducted at Eglin Air Force Base. A number of trials were conducted wherein the smoke pots were operated in a rapid pulsing fashion so as to produce a single dense composite puff to provide a rapid obscurant system (ROS) function. In these trials, six chambers at a time were functioned with a firing interval of 0.1 seconds between each sequential chamber initiation. In this manner, three trials were obtained from a single smoke pot. The resulting composite puff from one such IR trial is shown in figure 9.

In other trials, the controller was set to provide a longer interval between pulses in such a manner so as to produce a continuous plume result over a longer duration of time. This is referred to as obscurant reinforcing system (ORS) function. In these instances, the a firing interval of either 1.7 seconds or 3.3 seconds was employed, giving an effective function duration "burn time" of either 30 seconds or 60 seconds for a single smoke pot. The screening curtain produced from a sequence of three IR chambers fired at a 3.3-second interval is shown in figure 10.

In all of the trials, the electronic controller performed adequately. The unit proved to be fast, simple and convenient to operate. Cloud measuring instrumentation was deployed at the Eglin AFB trials. However, at the time this manuscript is written, the reduced data is not available for publication. Difficulties in processing the raw measurements have delayed the availability of quantitative performance results.

Figure 9. Composite puff produced from a single salvo, 6-chamber quick burst.

Figure 10. Continuous curtain produced from a 3.3-second firing interval.

4. PRODUCT IMPLEMENTATION CONCEPTS

Disposable Smoke Pot - A low cost, disposable Smoke Pot would be advantageous in practice because it would reduce the usage cost allowing numerous units to be used in any given application. The use of preset parameters would minimize the sophistication of the control system. In doing this, the display and switches could be eliminated. A single switch would initiate the safe wait delay and the subsequent chamber initiation sequencing. The complexity of the controller assembly would be significantly reduced. The prototype controller uses batteries for its source of power. The disposable unit could utilize a storage capacitor charged by a separate re-usable charging unit just prior to operation. These measures, in combination with high volume manufacturing techniques, could produce a disposable device having a cost below $500 per unit.

Vehicle Protection - To provide ground vehicle self-protection against direct fire combat, the smoke pot system could be used as an onboard, mobile ORS or ROS screening application. The smoke pot dispenser technology could be adapted to either a fixed installation mounting or a two-axis motor driven turret. In this application, the smoke produced by the dispensers is closely coupled to the vehicle. Dispenser hardware concepts and mounting arrangements are shown in figure 11. In these applications the firing control is integrated with the vehicle threat detection sensors and countermeasures system. Empty dispenser units may be replaced quickly in the field. It would also be possible to devise an autoloader for this application.

Projected Smoke Cartridges - The multiple chamber smoke pot configuration could be adapted as a launcher unit for projected cartridges. The mono-block unit would house 18 individual cartridges that would be launched out of the dispenser by a gas generating impulse cartridge in a manner similar to chaff and decoy cartridge dispensers used on aircraft. The hot ejection gases initiate a pyrotechnic delay element. At the end of the delay element burn, the obscurant expulsion charge inside the cartridge would be initiated, producing a smoke cloud. Using a turret aimed launcher, the projectiles are aimed in the direction of the incoming threat. This is illustrated in figure 12. As with the previous concept, the control system is integrated with the vehicle threat detection sensors and countermeasures system. In this application, it is important that the cartridges produce no hazardous shrapnel that could cause injury to dismounted soldiers operating in close proximity to these vehicles.

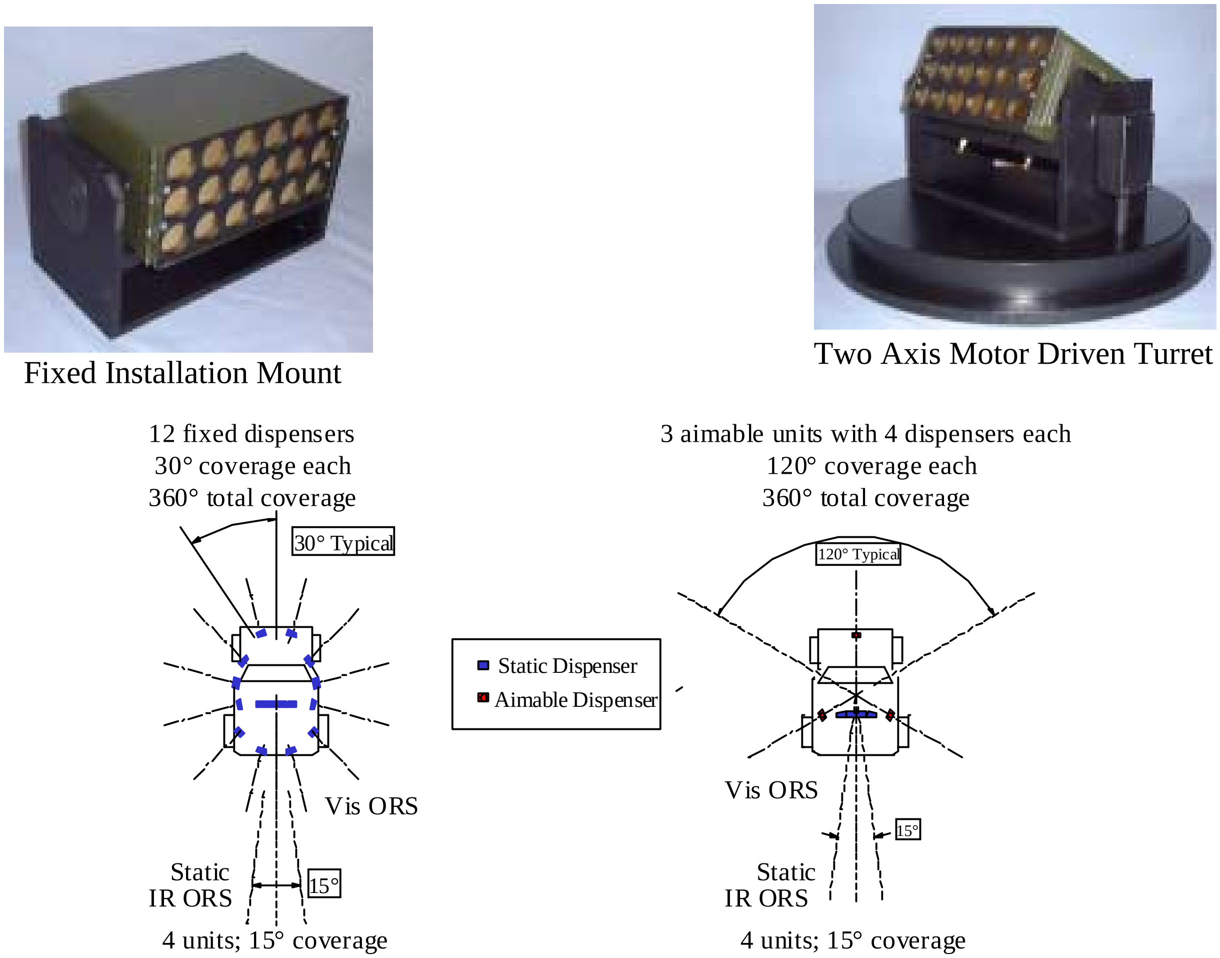

Figure 11. Vehicle self-protection obscurant countermeasure application.

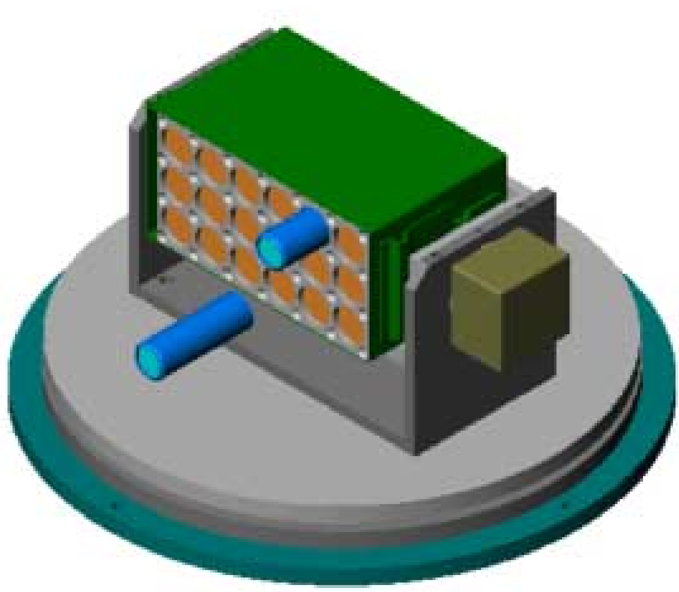

Figure 12. Adaptation of smoke pot as a launcher for projected screening cartridges.

Daisy Chaining - For ground based usage, the application of the basic Smoke Pot capability could be enhanced by adding the ability to daisy chain multiple Smoke Pots in an array. As illustrated in figure13, each Smoke Pot would feature an additional connector that allows multiple units to be connected together into a network. The network would consist of a single master unit (a smoke pot in itself) and any number of slave units. The master unit would be programmed by the user to define how the slave units are to function. Long patch cables would allow the slave units to be spaced apart and arranged in some pattern, providing a larger area smoke screen. The pots could be set to function in sequence; or they could be set to function simultaneously, or only a few cartridges from each in the first sequence, then the next few cartridges in the next sequence, and so on. One could even utilize slave units containing different obscurant types for a multi-spectral setup. These few examples should provide the idea that, with this networking concept, the functional combinations are limitless and can be arranged to best suit the screening application.

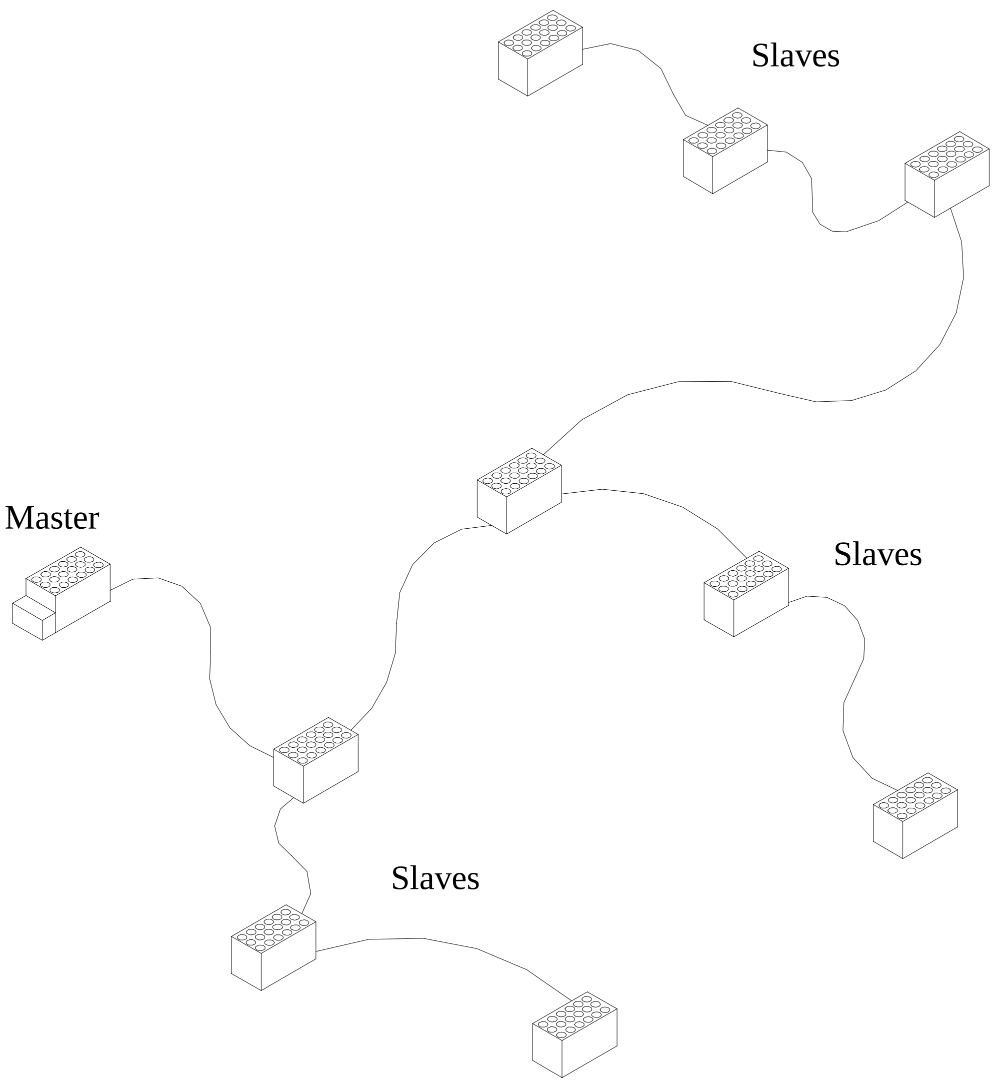

Figure 13. Smoke pot network, interconnect system.